Dendrogeomorphological Investigation of Earthwork Stability at Poverty Point State Historic Site, Louisiana

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Abstract

All mature hardwood trees were cut and removed from the major earthworks at Poverty Point National Monument and Louisiana State Historic Site in 2011 and 2012 due to concerns about erosion associated with the uprooting of soil upon tree fall. This tree cutting provided an opportunity to use dendrochronology (tree-ring dating) in an attempt to estimate the erosion rate of selected earthworks, based on the increasing exposure of the near surface root system over time. A total of 205 separate tree stumps were numbered, mapped, age estimated in the field, and measured for the degree and type of root exposure. After a series of measurements were made on the exposed roots, 100 cross sections were removed from exposed roots on Mound A and the contact with the modern mineral soil surface was precisely marked on the side of each root. An exactly dated tree-ring chronology was developed from selected white oak trees cut at the Poverty Point site. This master chronology was based on 16 radii from 8 trees and dates from 1855-2010. The white oak chronology was used to date the year of root exposure for 19 separate roots, and ring counts were used to closely estimate root exposure date on another 27 roots (46 total dates and estimates). All of these dated and ring counted roots had been exposed on the surface of Mound A before the trees were felled. The remaining roots were too young or the rings were too distorted or decayed for precise estimation of the year of exposure.

A modification of the method developed by Gartner (2007) was used to measure soil loss (or accumulation) at each dated or ring-counted root. The analyses of the 46 roots indicate that they were exposed more or less continuously over the past 62 years, with a peak in exposure during the 1980s. The average year of exposure was 1983 for the 19 tree-ring dated roots (1983.4) and 1982 for the 27 ring-counted roots (1982.6). The earliest and latest dates of ring exposure were 1949 and 2003, respectively (based on exact dating and ring counting). The average soil loss associated with this sample of 46 dated and ring-counted roots was estimated to be slightly negative, meaning no soil loss or perhaps very slight soil accumulation [i.e., mean thickness of the eroded soil (E_s) = -0.6 cm, standard deviation = 2.12 cm]. The estimated soil thickness change should probably be regarded as zero in light of the large variance in the estimate and the imprecision of the measurements at the sub-centimeter scale. A few roots did record

evidence for soil loss (i.e., positive values of E_s), which might indicate local areas of soil loss on Mound A. However, several other roots recorded large negative values for E_s indicating that soil may have accumulated around these particular exposed roots during their lifespan (perhaps due to down slope soil movement). Alternatively, some sample roots may literally have grown out of the ground at a rate faster than the rate of any soil that may have accumulated. We favor the latter interpretation for the negative values of E_s and speculate that many sample trees on Mound A experienced buttress growth of exposed roots on the down slope side of the tree to maintain vertical growth of the stem on the steep slopes.

Our results indicate that there may be a species effect on the estimation of soil loss on Mound A at Poverty Point. Most of the large negative soil change estimates were calculated for white oak roots, and most of the large positive soil surface changes were calculated for other species. The sample size of dated and ring-counted roots is too low for a rigorous test this species-specific soil loss hypothesis, but experiments might be conducted in similar soils to identify the native tree species potentially useful for erosion estimation based on the degree of root exposure.

Introduction

In 2011 hundreds of mature hardwood trees were cut and removed from the ancient mounds at the Poverty Point National Monument, Louisiana, in an effort to minimize erosion of the earthworks associated with tree fall (Figure 1). The cut stumps and roots on the mounds provided a unique opportunity to investigate the potential to use tree-ring dating of exposed roots to estimate slope erosion rates on the earthworks during the life of the felled trees. A research design was developed to test the hypothesis that erosion could be measured with tree-ring dating of the time of root exposure, coupled with careful measurements of the amount of soil lost from the roots since the time they were exposed.

Tree-ring specimens extracted from a subset of white oak trees felled at the site (Figure 2) were used to develop a master tree-ring chronology for the Poverty Point site. Accurate age data were also collected from the cut surfaces of 205 separate trees felled from Mound A (i.e., careful ring counts were obtained in the field). Root cross-sections were cut from 100 separate roots emanating from 40 different trees (stumps) on Mound A. The amount of exposure above the modern land surface was carefully measured for these root specimens during field sampling. Root age and year of root exposure were determined in the laboratory with dendrochronology. The dated ring widths on a subset of root specimens were measured. The amount of soil eroded for each exposed root was calculated using a modified version of the methods described by Gartner (2007).

This report describes the fieldwork, laboratory methods, data processing, and results. The results do not indicate a measurable amount of soil erosion during the relatively short time period that could be investigated with the exposed roots on Mound A. The problems encountered during this research and potential for future research are also discussed.

Data and Methods

The dendrochronological fieldwork was conducted at Poverty Point during two time periods, May 16-18, 2011, and January 15-18, 2012. Fieldwork began with careful ring counts to determine tree age on over 200 freshly cut stumps on Mound A. These cut stumps represent various hardwood species with a relatively fast growth rate, so that tree age could be determined accurately in the field on the well-exposed surface of most cut stumps. All stumps were first numbered, mapped, and identified to species or genus. Age determinations were then made. Any exposed roots for a particular stump were measured for maximum length and diameter. Exposed roots were counted using a four-quadrant system where quadrants A and B were arranged upslope from the main stump and quadrants C and D down slope (the stump was positioned in the center of the four quadrants). The data recoded for the stumps and roots are presented in the Excel workbook titled PPWorkbook.xlsx.

Small excavations were required to extract the root cross sections with a chainsaw (Figure 3). Root cross sections were carefully extracted and labeled after measuring distance to the cut from the stump, diameter at cut, excavation width, length, and depth, along with remarks on slope angle. The soil contact location on the exposed root was marked on both sides of the root with ceramic nails and indelible ink. A total of 100 root samples were taken from 40 different trees of various genera including *Quercus*, *Prunus*, and *Carya* (data presented in Sheet 3 of PPWorkbook.xlxs).

The root and stem cross sections were further processed at the University of Arkansas Tree-Ring Laboratory. All samples were sanded to a fine polish to expose the wood anatomy (Figure 4). The white oak cross sections were crossdated with each other using the skeleton plot method to account for missing or false rings (Stokes and Smiley 1995). A composite chronology was developed for the Poverty Point white oak specimens and was then compared to preexisting chronologies in the region to confirm the exact calendar dating of all rings. The dated ring widths on the Poverty Point white oak specimens were measured with the precision of 0.001mm (measurements available in Sheet 6 of PPWorkbook.xlxs). The exactly dated ring-width measurements were submitted to the quality control program COFECHA (Holmes 1983) to statistically verify the crossdating. Using the program ARSTAN (Cook and Peters 1981, Cook et al. 2007), the raw measurements were detrended using a spline curve with a 50% frequency response of 50 years, the ring-width indices were computed by division of the measured ring-width value by the value of the fitted curve for each year, and the numerical 'standard' chronology was computed as the robust mean of all available ring-width indices each year. Finally, the variance of the derived chronologies was stabilized using a smoothing spline with a 50% frequency response of 100 years. The detrended ring-width indices are presented in Figure 5. The mean ring-width and standardized ring-width chronologies are illustrated in Figure 6, along with the sample of dated specimens each year. The numerical ring width data and derived chronologies are included in the Excel workbook (PPWorkbook.xlxs).

Multiple measurements were taken from the root samples using a modified version of the method described by Gartner (2007). These measurements and the equation used to compute the total depth of soil eroded from exposed roots (E_s or EsRm) are described in Figure 5. The root samples with sufficient growth rings for tree-ring crossdating were dated against the master chronology for Poverty Point. When possible, the inner and outer ring dates, and the year of root exposure were exactly dated and labeled on the root samples. The ring-width series on some root specimens were too distorted or otherwise compromised to permit exact dating, but in many of these cases approximate dates could be determined using simple ring counts.

The approximate location in the ring sequence on the polished roots where exposure occurred was determined on the basis of field observations that marked the surface of the mineral soil on the edge of the root. Several ring width and anatomical features preserved on the exposed root specimens then helped to specify the exact year of exposure, and these ring width features generally agreed closely with the field observations on the point of exposure. None of these ring width or anatomical features were universally present on all the exposed roots, and they are listed below by their approximate frequency and usefulness:

1. an increase in ring width at or soon after exposure,
2. discoloration of the polished wood at the point of exposure,
3. a change from more or less diffuse porous to ring porous wood anatomy at the time of exposure (on ring porous species only),
4. thickening of the latewood zone upon exposure, sometimes including tangential bands of fiber cells,
5. an increase in vessel diameter on recently exposed root wood,
6. scarring of the cambium and a wound response on the upper surface of the root near the time of exposure.

A subset of the dated roots was also measured with 0.001mm precision (Sheet 10 of the PPWorkbook). Some of these root-ring measurements are illustrated in Figures 12-15, along with photographs of the corresponding roots.

Results

We obtained ring-counted age estimates for 179 separate trees at the Poverty Point site, mostly on or near Mound A. These trees averaged 67.2 years old at the time they were felled, but ranged in age from 40 to 156 years old (Sheet 7, PPWorkbook.xlxs). These estimates are based only on ring counts, but are certainly close to the true germination age of these trees because most trees were cut flush near the ground surface, the species were mostly ring porous, the growth rate was rapid, the rings were very well defined even on the chain saw cut surfaces, and the counts were made carefully (with magnifying glass when necessary).

The individual chronologies for 16 tree-ring dated white oak radii (all probably *Q. alba*) are plotted in Figure 5 and illustrate the strong crossdating of interannual ring-width variability among these sample trees and radii. The standard tree-ring chronology derived for white oak at the Poverty Point site is plotted from 1855 to 2010 in Figure 6. The radial growth of most upland oak species in the southcentral United States tends to be positively correlated with precipitation and negatively correlated with temperature during the growing season (Blasing et al. 1988; Stahle and Cleaveland 1988; Haavik et al. 2011). The tree-ring chronology developed for white oak at Poverty Point is correlated with other oak chronologies from Arkansas (e.g., r = 0.43 for a comparison between the Poverty Point and Lake Winona, AR, white oak chronologies for the period 1901-1980). We have not specifically modeled the climate signal in the white oak chronology from Poverty Point, but the chronology certainly records some of the major droughts that afflicted northeast Louisiana during the 20th Century (e.g., 1918, 1925, 1955, 1956, 1988, 1998, and 2000; Figure 6; growing season droughts identified in the instrumental Palmer Drought Severity Indices for Louisiana Climate Division 2, National Climatic Data Center, NOAA).

The derived 156-year long chronology was useful for dating the roots of all available species from Mound A. The tree-ring analyses of the 46 dated and ring-counted exposed roots indicate that near surface roots were exposed on Mound A from 1949 to 2003 (Figure 7). Most roots were exposed in the 1980s and the average tree-ring date of root exposure was in the year 1983 [i.e., 1983.4 based on 19 exactly dated roots (Sheet 4, PPWorkbook.xlxs]. The average date of root exposure for the 27 ring counted roots was also 1983 (i.e., 1982.6). There does not appear to have been a strong age effect on root exposure at Mound A (Figure 8). The average age of the 28 roots that could be dated to pith (or closely approximated to pith with limited ring counts) was 22.4 years, but the ages of individual roots range from 6 to 46 years.

The methods used to compute the amount of soil loss to erosion around each dated root are illustrated and described in Figure 9. The methods were adopted with minor modification from Gartner (2007). The key computed value is the amount of eroded soil (E_s in equation 1 presented in Figure 9, also calculated as EsRm and EsR1 in the PPWorkbook.xlxs). Positive values of E_s indicate that soil eroded around the exposed roots. Negative values of E_s could indicate that soil either accumulated around the exposed roots or that the root actually grew out of the ground at a rate faster than the rate of change in the soil surface (i.e., soil accumulation or erosion).

The results presented in Figure 10 indicate that there is no strong evidence for soil erosion from Mound A during the life of the sample roots, which only covers the last 60 years (see also Sheets 4-6, PPWorkbook.xlxs). The overall mean change in the soil surface on Mound A over the life of the available dated roots was -0.6 cm, with a large standard deviation of 2.12 cm. These results suggest a slight accumulation of soil around our sample of exposed roots. However, the computed mean value of -0.6 cm should probably be regarded as zero given the large variability in the individual root measurements and the difficulty of precise sub-centimeter scale measurement of the time root exposure and the amount of change in the soil surface. Many of the computed values of E_s are very close to zero, meaning no detectable change in the soil surface (Figure 10; see also Sheets 4-6, PPWorkbook.xlxs). There are a few large positive values of E_s in Figure 10, which might represent local soil erosion near those particular trees. But these few positive values of E_s are counteracted by a number of very large negative values. We doubt that soil is actually accumulating around these exposed roots during this short time interval, and instead speculate that some of the roots actually grew out of the ground to buttress the stem on the steep slopes of Mound A.

Our results indicate that there may be a species effect on the estimation of soil loss on Mound A at Poverty Point. Most of the large negative soil change estimates were calculated for white oak roots, and most of the large positive soil surface changes were calculated for other species (Sheet 6, PPWorkbook.xlxs). The sample size of dated and ring-counted roots is too low for a rigorous test of this species-specific soil loss hypothesis, but experiments might be conducted in similar soils to identify the native tree species potentially useful for erosion estimation based on the degree of root exposure.

The total number of roots exposed for each quadrant A-D for all the stumps sampled on Mound A is tabulated in Figure 11. The results indicate that 69% of the exposed roots were located in the C and D quadrants, down hill from the parent tree. These results are not statistically significant in a 2x2 contingency table analysis (Figure 11), but might nonetheless suggests that some soil accumulated on the uphill side of the tree stems due possible to colluvial damming (in the A and B quadrants). At the same time, interruption of down slope soil movement and soil erosion could account for the higher frequency of exposed roots downhill from the main stem (C and D quadrants). Alternatively, vigorous root growth out of the ground at a rate faster than the rate of change in the soil surface might also explain the results in Figure 11, perhaps as a buttress or reaction wood response to steep slope conditions.

The raw ring-width measurements for four different root samples are plotted along with photographs in order to display the anatomical features associated with root exposure (Figures 12 -15). The raw ring-width measurements plotted for the *Quercus* root samples PP01B, PP02A, and PP15B show a surge in ring-widths at the year of exposure identified from field observations of the soil contact and consistent with changes in ring anatomy. However, it was not possible to use this method to estimate soil loss for some root samples in the collection due to severe scarring and subsequent reaction wood formation, or the occurrence of multiple piths within the cross section (Figure 16).

Conclusions

The results of this analysis are equivocal and do not provide strong evidence for soil erosion from Mound A at Poverty Point during the lifetime of the sample trees and exposed roots. The average change in soil thickness calculated from the exposed roots is slightly negative (mean E_s = -0.6 cm), indicating a very slight soil accumulation around the sample roots. This estimated change in soil thickness adjacent to the exposed roots is unlikely to be significantly different from zero given the large variance in E_s among the sample roots (standard deviation of E_s = 2.12 cm). Positive values of E_s were calculated for some roots and may indicate localized areas of soil erosion on Mound A. Alternatively, some tree roots may have actually grown out of the ground, especially in the down slope direction, in effect buttressing the tree to maintain an erect stem on the steep slopes.

A number of practical problems made it impossible to precisely determine the anatomical transition from root wood to stem wood on the polished cross sections of some roots, including severe scarring, reaction wood formation, and the presence of multiple piths (Figure 16). The majority of the root samples were taken from white oak trees. When E_s was calculated for all non-oak species (i.e., *Prunus* and *Carya*), the results were slightly positive (i.e., mean E_s = 0.3 cm, standard deviation = 2.62 cm, for just 13 roots). Although the sample size is very low, these results might suggest a species effect on the registration of root exposure. Indeed, eight of the nine most negative values of E_s were calculated for white oak trees (Sheet 6, PPWorkbook.xlxs), suggesting a potential buttress growth response to steep slopes in that species. An experimental study might be conducted on similar soils in the region to identify the native tree species potentially useful for erosion estimation based on the degree of root exposure. Depending on the results of such a study, a reanalysis of the Mound A root samples might then be warranted.

References

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Figure 1. Mound A at the Poverty Point National Monument and Louisiana State Historic Site is illustrated before and after tree removal, October 2010 (top) and May 2011 (bottom).

Figure 2. Cross sections were cut from white oak logs recently felled at the Poverty Point site and were used to develop a master tree-ring chronology (both white and red oak logs are illustrated in this photo). The white oak chronology was then used to date exposed roots in an attempt to measure erosion rates on Mound A.

Figure 3. Root samples were extracted after labeling the ground-surface contact and taking measurements of root dimensions and the width and depth of the shallow excavations. The ceramic nails were inserted where the root made contact with mineral soil.

Figure 4. A subset of the sanded and tree-ring dated white oak cross sections from the Poverty Point site is illustrated in the top photograph. A selection of polished root cross sections from Mound A is illustrated below.

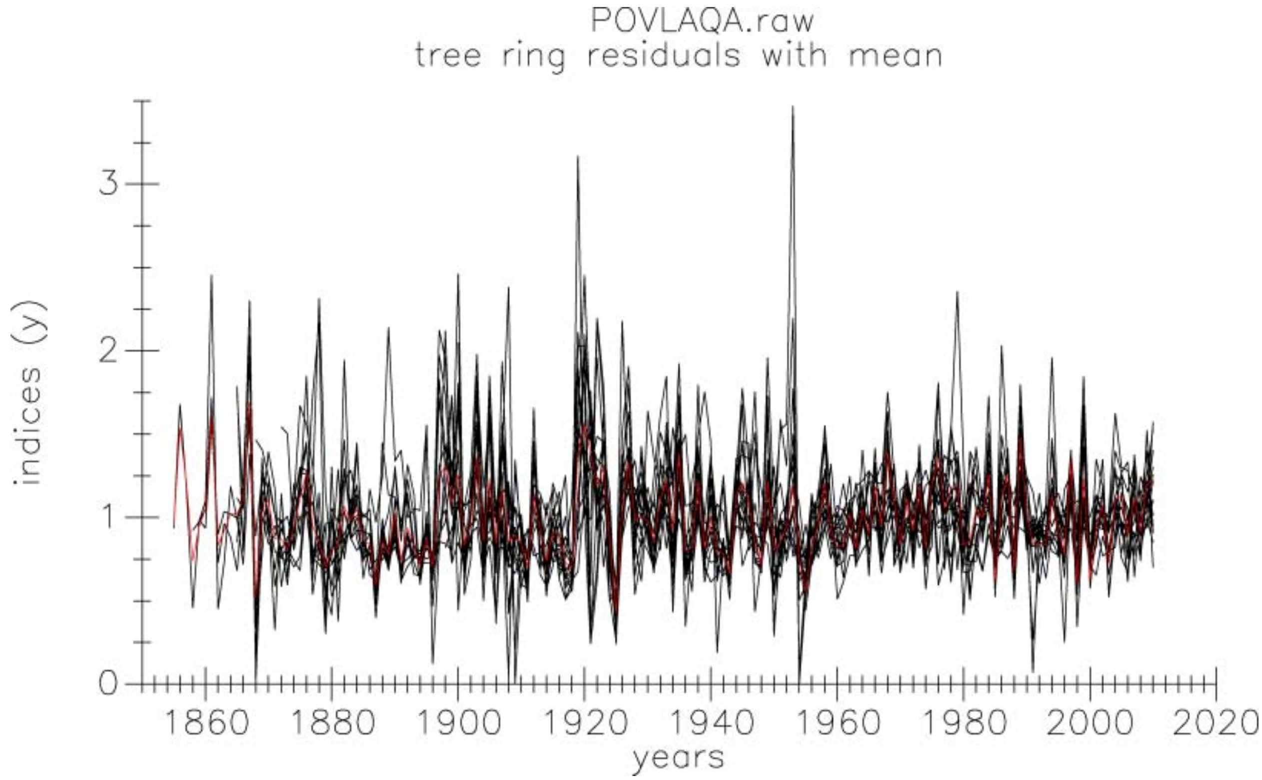


Figure 5. The individual dated ring-width time series (black lines) are plotted with their mean (red series), after detrending and the removal of low-order growth persistence (Cook et al. 2007). Note the strong correspondence among the individual time series, especially during the severe and widespread droughts of 1925, 1955, and 1985 over the southern United States [the average correlation among the 16 ring-width time series is +0.41 (RBAR, Cook et al. 2007)]. This chronology was used to date many of the ring series evident on the highly polished cross-sectional surfaces of exposed roots from Mound A at Poverty Point.

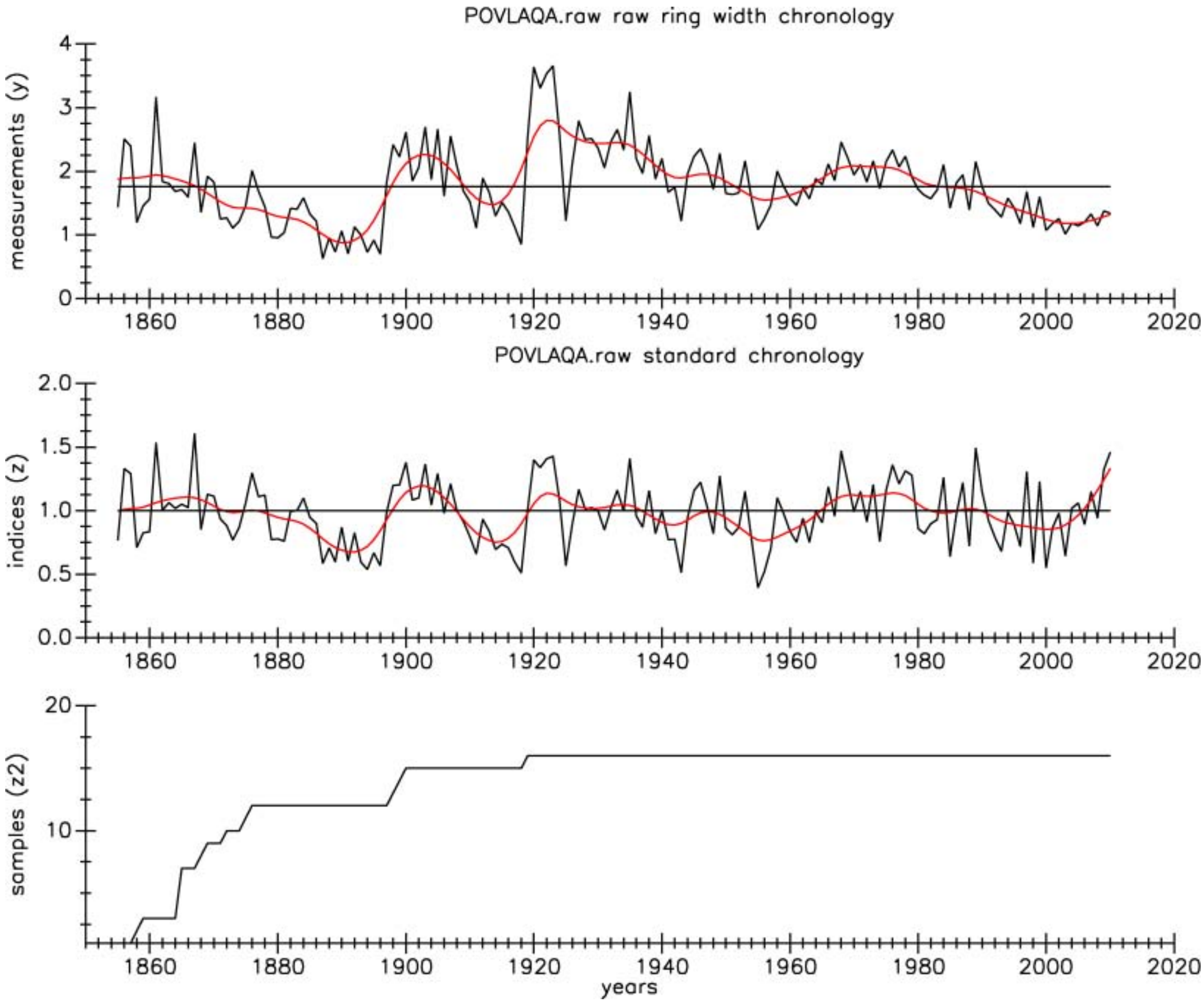


Figure 6. The mean ring-width chronology for the 16 white oak series from Poverty Point is plotted from 1855-2010 (top plot, in mm, without any detrending or standardization). The standardized ring width chronology for Poverty Point is plotted in the middle time series, after detrending and standardization (achieved by fitting a smoothing spline with a 50% frequency response of 50 years to the raw measurements and dividing the measured ring width value by the value of the fitted curve at each year, Cook and Peters 1981; Cook et al. 2007). The sample size for each year is plotted in the bottom series (i.e., the number of dated radii per year). Drought years and poor growth are indicated in the middle plot by values below the mean of 1.0, wet years and favorable growth by values above the mean. Note the low growth in 1918, 1925, 1943, 1954-1956, 1985, 1988, 1998, and 2000.

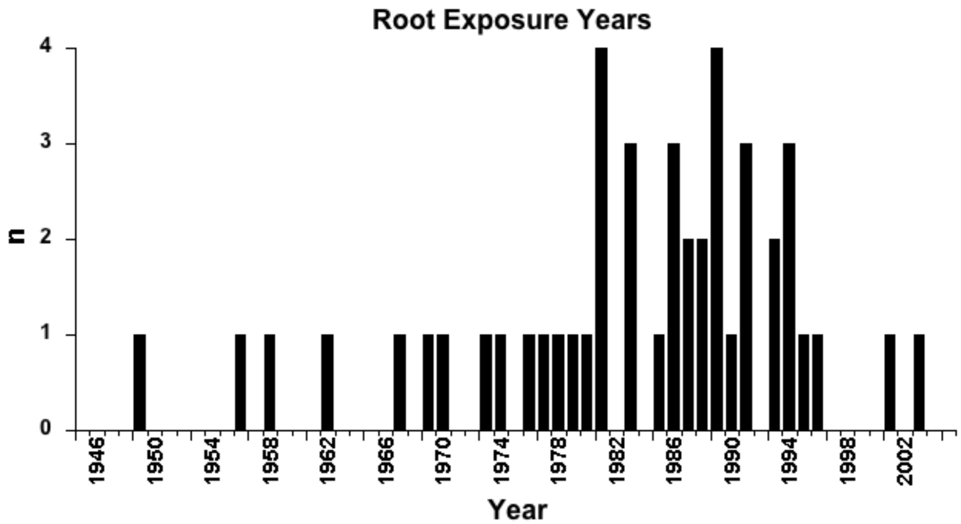


Figure 7. The tree-ring dated and ring-counted years of root exposure for 46 separate roots from Mound A at Poverty Point are plotted over the past 62 years (1945-2005). The dates of exposure range of 1949 to 2003, but peaked in the 1980s.

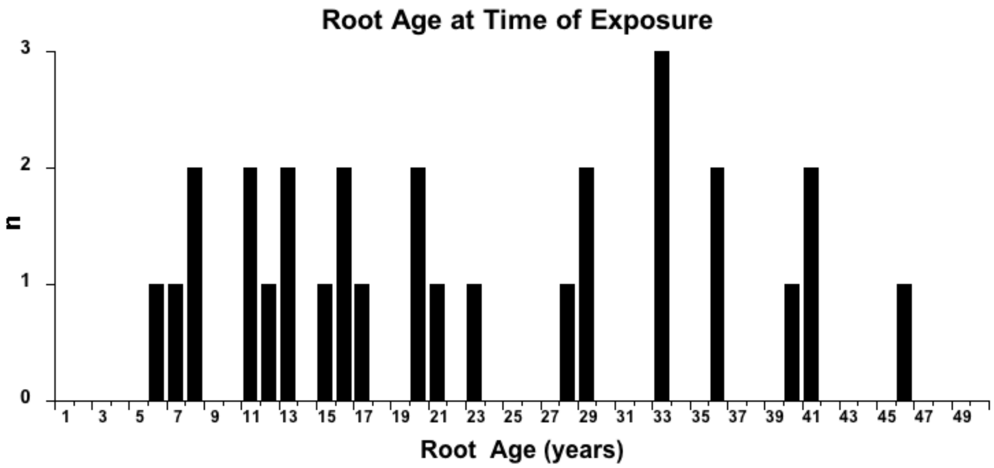
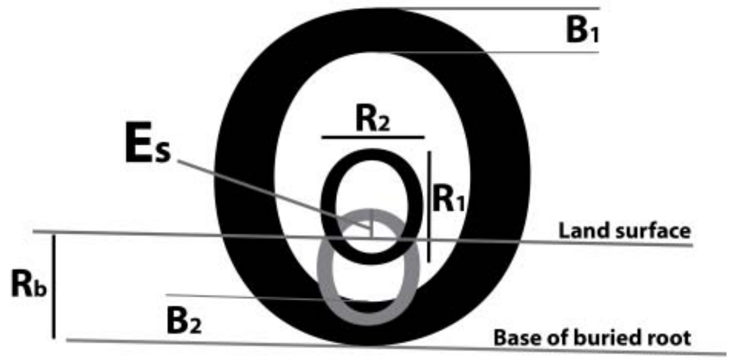


Figure 8. The age of each root at the time of exposure is plotted for 29 roots, most of which were exactly dated to pith or involved only a minimal ring count to pith. The average age of these dated roots at the time they were exposed at the soil surface was 22.4 years, but the range was from 6 to 46 years.

Total Eroded Soil Diagram



(1) $$E_s = [R_m + (\frac{B_1 + B_2}{2})] - R_b$$

Figure 9. Schematic diagram of a root cross section with the measurements used to calculate the amount of total soil lost. In the illustration **R1** = maximum root diameter at year of exposure (not including bark); **R2** = minimum root diameter at year of exposure (not including bark); **Rm** = mean of R1 + R2; **B1** = thickness of upper bark; **B2** = thickness of lower bark; **Rb** = depth of buried root at time of sampling (from base of root to modern soil surface, including the mean bark thickness). In the equation [(1), above], **Es** = thickness of eroded soil using **Rm** as the average of the original root diameter at the time of exposure. The quantity **EsRm** (listed in the Excel spreadsheet titled PPWorkbook.xlsx) = eroded soil thickness based on mean root diameter. The quantity **EsR1** (also listed in PPWorkbook.xlsx) = the thickness of eroded soil using **R1** instead of **Rm** in Equation 1. EsR1 was computed as an alternative estimate of soil loss to EsRm because the roots could be asymmetrical in the vertical dimension, and taking the mean diameter (EsRm) might therefore underestimate soil loss (little difference between the average of EsRm and EsR1 was observed (-0.6 vs -0.46, respectively). These methods have been adapted from Gartner (2007). It should be noted that positive values of Es (or EsRm or EsR1) indicate soil loss around the exposed root, but negative values could indicate either (1) soil accumulation around the root, or (2) the actual secondary growth of the root out of the ground at a rate faster than the rate of change in the soil surface, a growth response that might effectively buttress the tree stem on steep slopes.

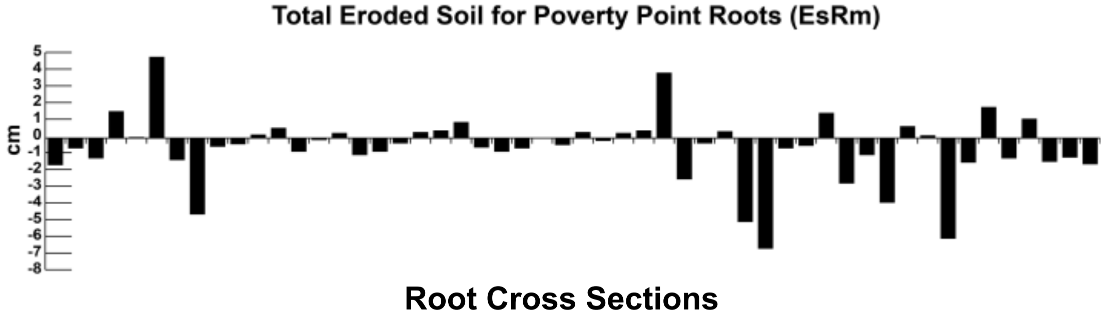


Figure 10. Total eroded soil values in cm calculated using Equation 1 are plotted for 52 root cross sections (here Es = EsRm; only 46 of these 52 roots could actually be dated). Each bar represents the amount of change in the soil surface measured from one root. Positive values represent soil loss and negative values would indicate soil accumulation or root growth out of the ground at a rate faster than the rate of change in the soil surface (data available for each individual root in Sheets 4-6, PPWorkbook.xlsx). The average value for the 46 dated roots is -0.6 cm.

Total Root Count by Quadrant

A **64** **upslope**	**B** **85** **upslope**
C **166** **down slope**	**D** **166** **down slope**

Figure 11. Total number of exposed roots counted in each quadrant for all sample trees on Mound A. The stump was at the center of the four quads. The A and B quads were on the upslope side of the stump, C and D were on the down slope side. The C and D quadrants contained 69% of the total number of exposed roots on the mound, indicating either 1.) more erosion on the down slope side of the trees, 2.) buttress growth of the down slope roots out of the ground, or 3.) preferential burial of the upslope roots by down slope soil creep. However, the higher frequency of exposed roots in the down slope direction is not statistically significant, based on a two-tailed P value computed in a 2x2 contingency table analysis of these data (P= 0.1675; http://graphpad.com/quickcalcs/contingency1.cfm).

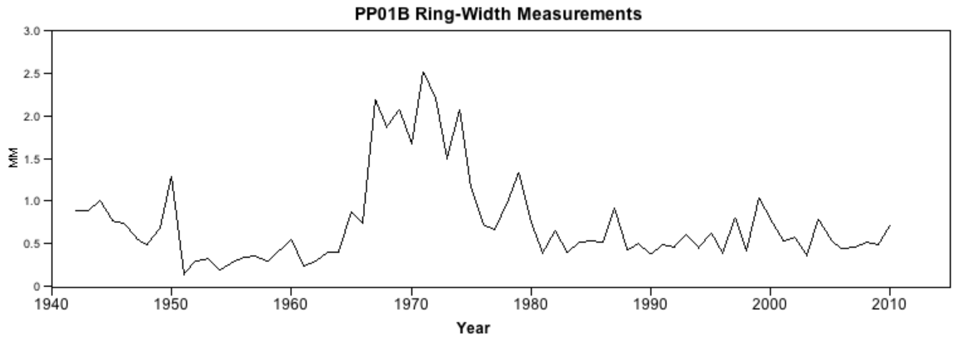
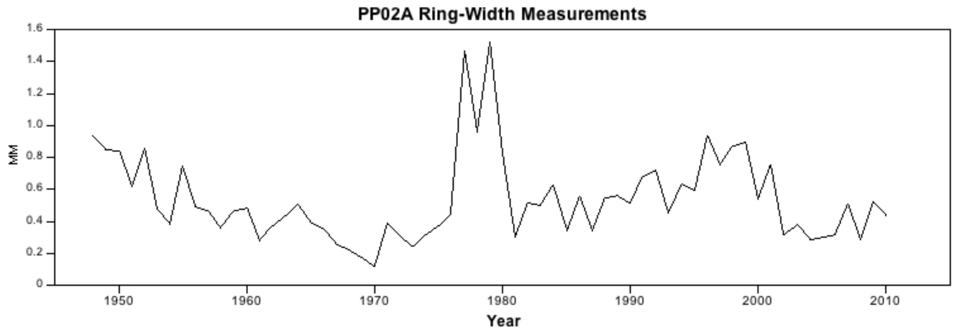


Figure 12. The raw ring-width measurements are plotted for oak root sample PP01B (top, in mm). A portion of the polished surface of specimen PP01B is photographed, and the year of probable root exposure is indicated by the ceramic nail (left) and black line (center), dated to 1967 (specimen PP01B is exactly dated from 1967-2010, but only approximately dated from 1934-1966). Notice the dramatic increase in ring width following the probable year of root exposure (1967, top and bottom).



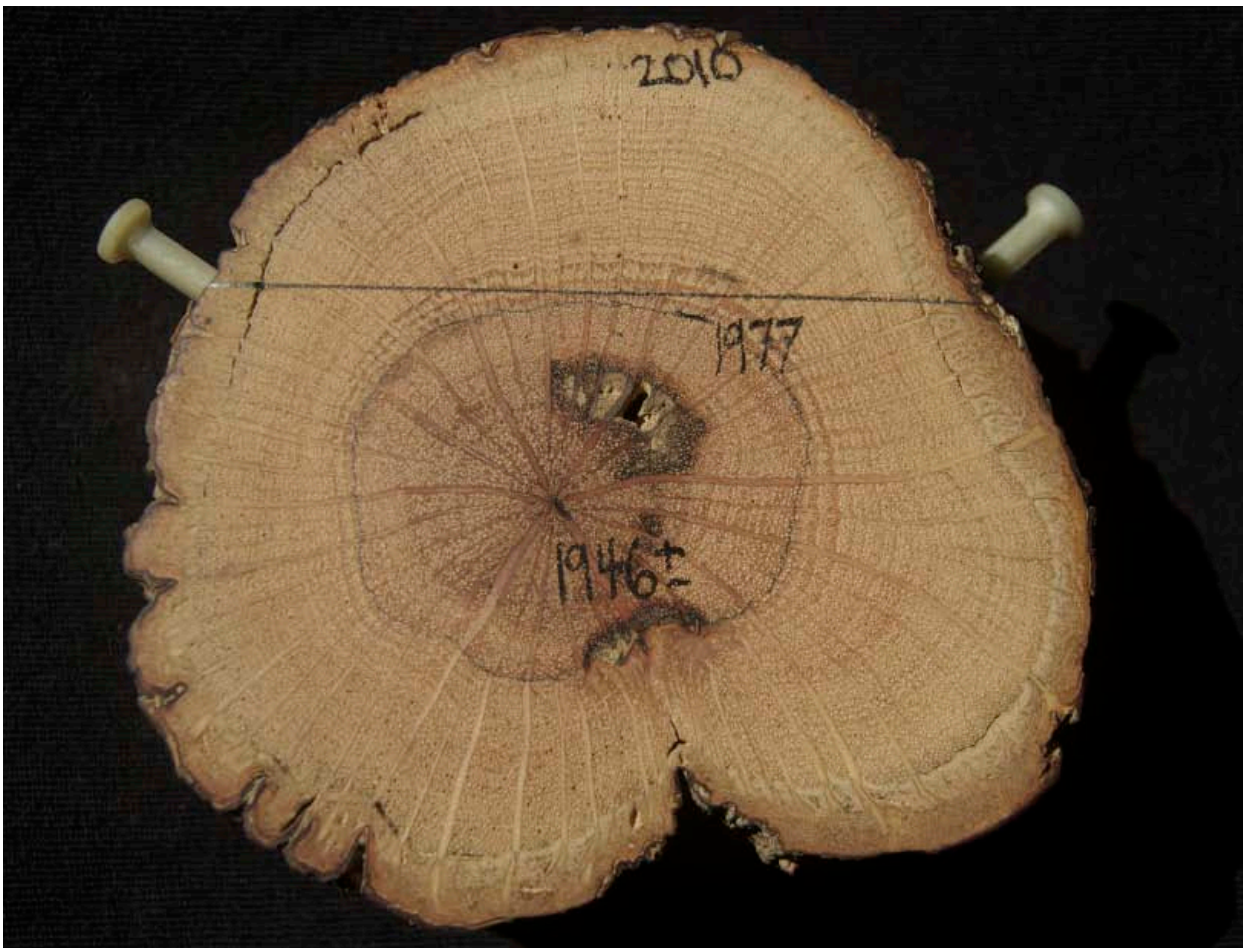
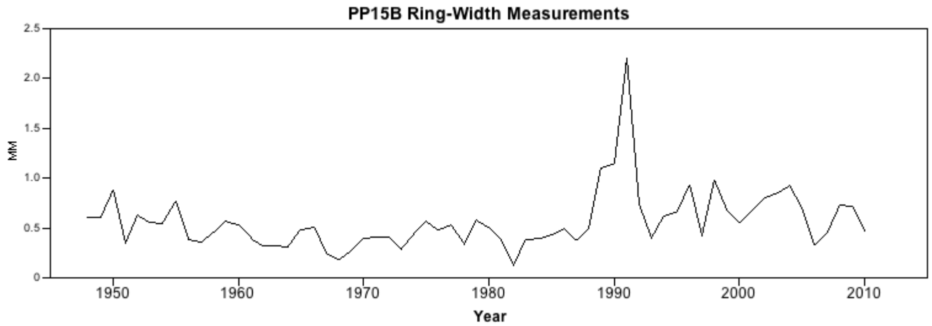


Figure 13. Raw ring-width measurements are plotted for white oak root sample PP02A (top, in mm). The ceramic nails indicate the soil contact at the time of sampling (bottom photograph, exact dating from 1977-2010, approximate dating from 1946-1976). The top portion of this root was exposed, above the ceramic nails. Notice the differences in bark thickness and ring anatomy between the stem wood (top) and root wood (below). There was a dramatic increase in ring-width following root exposure in 1977 (top and bottom).



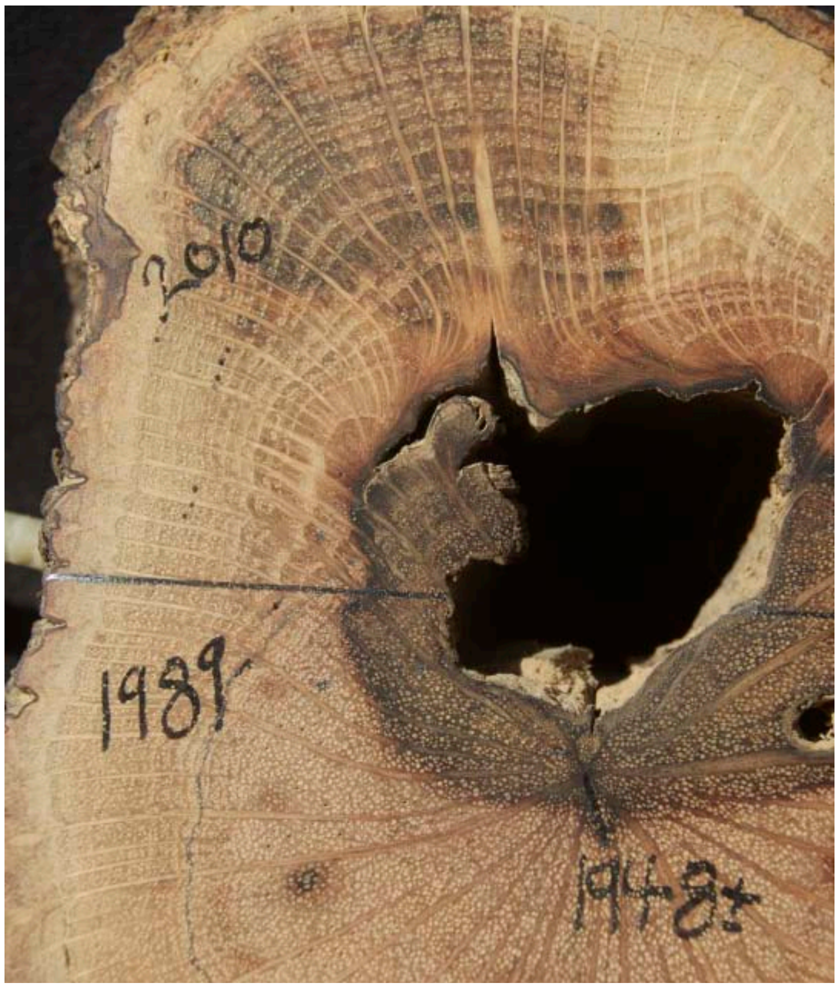


Figure 14. Raw ring-width measurements are plotted for oak root sample PP15B (top, in mm, exact dating from 1989-2010, approximate dating from 1948-1988). Notice the scar and surge in ring-width growth following root exposure, probably in 1989, in the photograph (bottom). The cambial scar and wound response may have been the result of physical damage to the exposed root surface.

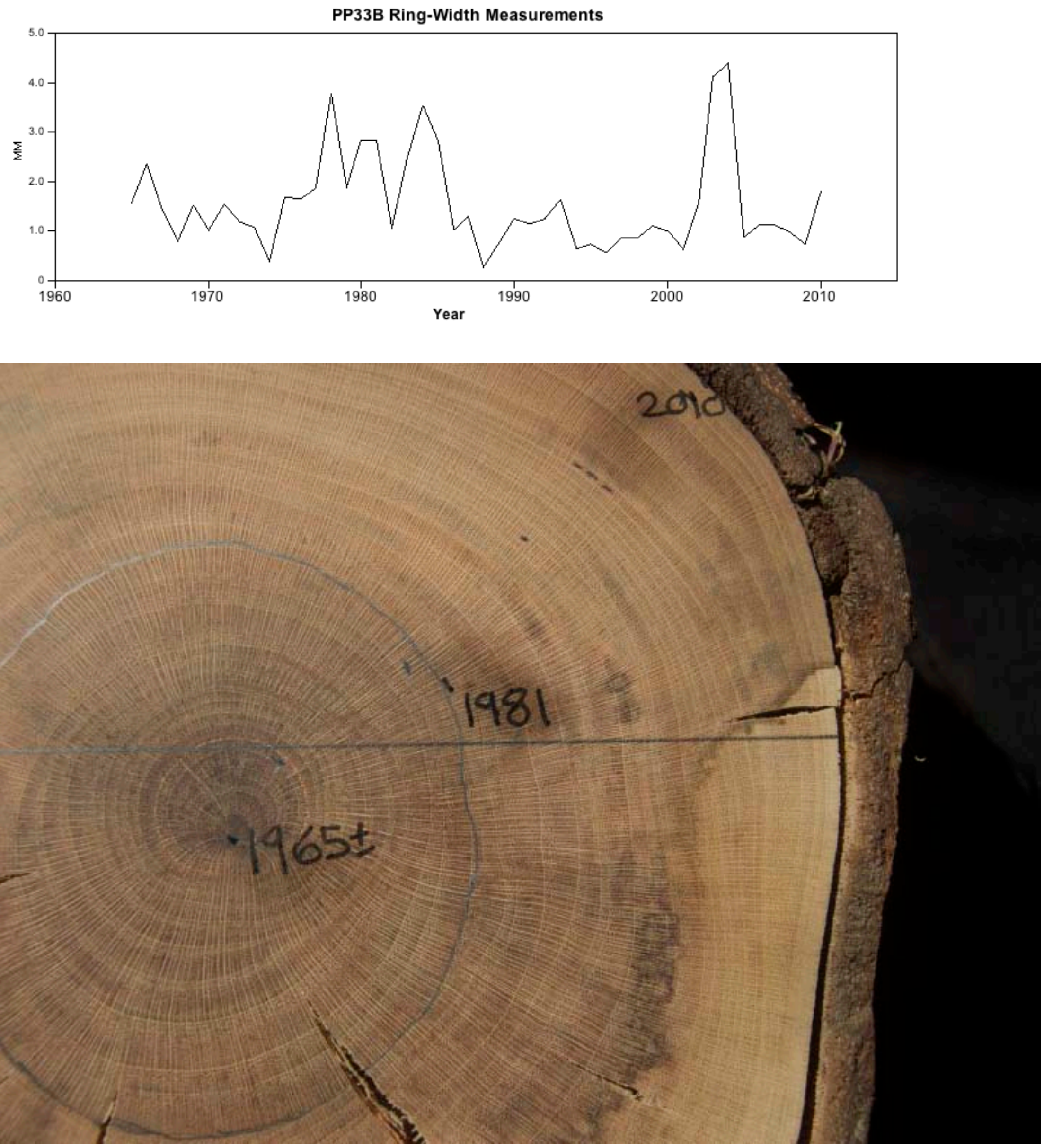


Figure 15. The raw ring-width measurements are plotted for the black cherry root sample PP33B (top; in mm). Dating is only approximate. This specimen does not exhibit a growth release at the year of exposure, believed to be approximately 1981 (ignore the horizontal pencil line).

Figure 16. Root specimen PP20B (top, white oak) sustained severe scaring and reaction wood formation, and could not be used to estimate the original ground surface or amount of soil erosion. Root specimen PP21B (bottom, hickory) included three separate piths, and could not be used to determine the year of exposure.